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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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A METALLURGICAL INVESTIGATION OF A CONTOUR-FORGED
DISC OF EME ALLOY

By E. E. Reynolds, J. W. Freeman, and A. E. White

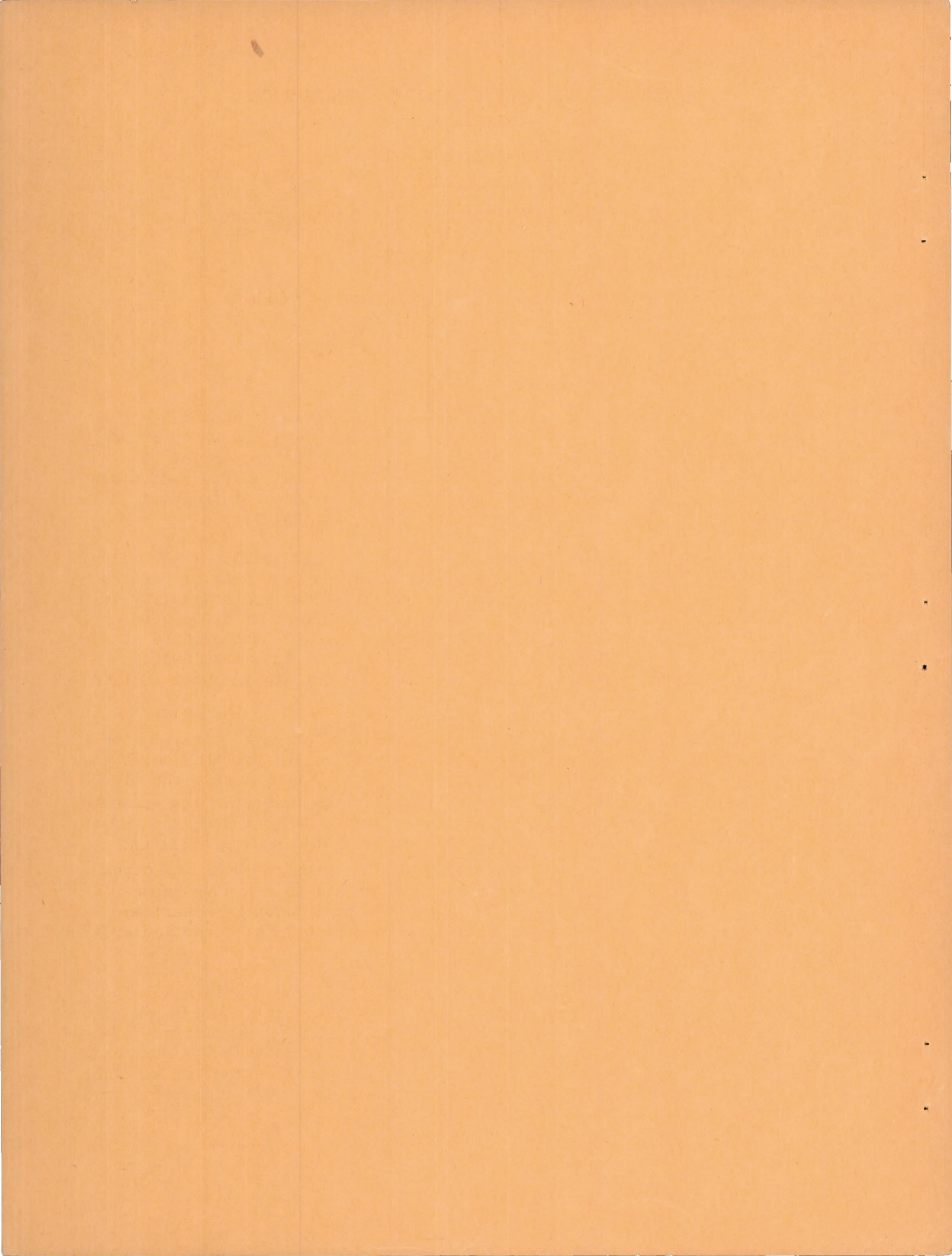
University of Michigan



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DISC OF EME ALLOY

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SUMMARY

The properties of EME alloy in the form of contour-forged discs for the rotors of gas turbines were studied. The investigation was part of a series of such investigations undertaken because the properties of promising alloys are dependent to a considerable extent on the conditions of fabrication, and the size and shape of the rotor discs introduced fabrication procedures for which information was not available.

The Midvale Company developed EME, which is a 19Cr-12Ni-3W-1Cb alloy. Studies by this company indicated that the alloy had suitable properties, particularly good forging characteristics and improved center quality in contour forgings, for large-size rotor discs. A number of discs were prepared from the alloy for experimental purposes. One was studied at the University of Michigan for the NACA. Additional data obtained by The Midvale Company and the General Electric Company are included in this report.

The discs tested in the original program were prepared early in the development of the alloy when sufficient experience had probably not been obtained to control forging conditions properly. Consequently, the disc tested was found to have low strength at 1200° F and somewhat low strength at room temperature. A similar disc tested by the General Electric Company had better properties, particularly at room temperature, but still had low properties at 1200° F in comparison with the properties of bar stock of the alloy and with similar forgings of other alloys. A disc subsequently prepared by The Midvale Company on the basis of more experience with the alloy had excellent properties at room temperature, particularly at the center of the disc.

The properties reported for the discs of EME alloy should not be considered as typical. They probably represent what could have happened to any alloy because of an unfortunate choice of forging conditions during early development. It is important to recognize that the reported results illustrate the importance of controlling the treatment of an alloy if the good properties of experimental bar stock are to be duplicated in commercial shapes.

Sufficient metallurgical experience and data were not available to determine the exact cause of the low strength of the discs. The optimum conditions of temperature and degrees of reduction for good properties at 1200° F were not maintained during forging. Probably these conditions interfered with precipitation reactions believed necessary for good strength at high temperatures. There was some evidence of variable and insufficient hot-cold-work for good strength.

INTRODUCTION

The EME alloy was developed for high-temperature service by The Midvale Company. It is an iron-base alloy with an analysis of 19 percent chromium, 12 percent nickel, 3 percent tungsten, and 1 percent columbium. Preliminary studies by The Midvale Company of the properties of EME alloy in the form of bar stock indicated that the alloy had possibilities for suitable service as rotors for the gas turbines of jet engines for aircraft. For this reason contour disc forgings were manufactured for experimental purposes. One-half of one of these forgings was submitted for study at the University of Michigan for the NACA.

Since alloys of this type depend to a large extent on the processing conditions, especially temperatures of forging and hot-cold-work, for their optimum properties up to 1200° F, the disc was prepared in the as-forged and hot-cold-worked condition. The principal objects of this investigation were to determine the level of properties developed in the type and size of disc actually used in service, to relate these properties to those of EME bar stock, and to evaluate the alloy on the basis of a comparison of its properties with those of similar discs of other alloys.

The properties of the disc were determined at room temperature and 1200° F. These are the two temperatures at which materials must possess satisfactory properties to meet the requirements of performance as rotor discs in current jet engines.

The disc of EME alloy is one of a series of discs of various alloys which are being studied. The results obtained from investigations on large discs of 19-9DL, CSA, low-carbon N-155, and Timken alloys are given in references 1 to 7.

This work was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

DESCRIPTION OF DISC

The available information concerning the disc of EME alloy is summarized as follows:

Manufacturer:

The Midvale Company, Philadelphia, Pennsylvania

Heat number:

H-4819

Chemical composition:

The reported chemical composition of the disc together with the preferred limits of analyses was reported to be the following percentages by the manufacturer:

	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>P</u>	<u>S</u>	<u>Cr</u>	<u>Ni</u>	<u>W</u>	<u>Co</u>	<u>N</u>
Disc	0.12	0.48	0.73	0.015	0.028	19.72	11.60	3.38	1.30	0.127
	0.12	0.40	0.40			18.75	11.50	3.00	0.85	0.10
Range	to	to	to	-----	-----	to	to	to	to	to
	0.17	0.60	0.60			19.75	12.50	3.50	1.25	0.20

Fabrication procedure:

The forging was made from a 2600-pound, 17-inch-diameter ingot which was cast from an arc-type basic electric furnace. The ingot was reduced to a $10\frac{1}{4}$ -inch-diameter billet and upset first under a press and then under a hammer to the dimensions shown in figure 1. Hot-forging was from 2050° to 2100° F, finishing at about 1700° F. The disc was hot-cold-worked by forging at 1240° F. The disc was then given a stress-relief anneal of 4 hours at 1200° F and air-cooled. One-half of the disc was supplied by The Midvale Company in cooperation with the General Electric Company.

Comments:

This disc was made during the early stages of the development of the alloy when work was being done solely to study the relative forgeability of the alloy. Subsequently work was undertaken to fix the optimum composition of the alloy and to develop the forging technique which would produce the most favorable mechanical properties both at room and elevated temperatures.

EXPERIMENTAL PROCEDURE

The following testing program for the one-half section of the disc of EME alloy was decided upon:

- (1) Tensile tests at room temperature and 1200° F
- (2) Rupture tests at 1200° F
- (3) Creep tests of 1000-hour duration at 1200° F under stresses of 17,500 psi and 20,000 psi
- (4) Hardness, tensile, and rupture tests to show the uniformity of the disc material
- (5) Stability tests on specimens after testing

The major emphasis was placed on the properties of radial specimens from near the rims of discs because the rim is heated to the highest temperature during service.

Data on stress and time for total deformation were obtained from the elongation curves from rupture and creep tests. There is little of this type of data for the EME disc, however, because the low strength of the disc did not warrant more than a limited number of creep tests.

Stability characteristics were estimated by hardness, tensile, and impact tests and metallographic examination on the specimens after creep and rupture testing.

In order to supplement the data obtained from the testing program, data on EME alloy reported by the General Electric Company and The Midvale Company laboratories have been included in this report.

The necessary test specimens were obtained from coupons cut from the disc as shown in figure 1. This drawing shows the location of the specimens and an identifying code. In this code X, Y, and Z refer to the locations of the coupons with respect to the faces of the disc. Tensile and creep tests were conducted on standard 0.505-inch-diameter specimens. The specimens for rupture tests were 0.160 inch in diameter and were obtained from locations in the large coupons as indicated by the dashed lines in the drawing of figure 1.

RESULTS

Hardness Surveys

The principal Brinell hardness range for the disc of EME alloy was 230 to 250, although some of the values were outside this range as is seen in figure 2 and table I. There appeared to be a soft spot in the

center of the disc near the stub shaft. In general the disc tended to be harder near the rim than near the center and near the two flat surfaces than in the interior.

Short-Time Tensile Properties

The tensile properties at room temperature and 1200° F are summarized in table I. The tensile strength and 0.02-percent-offset yield strength of radial specimens near the rim of the disc were approximately 112,500 and 74,000 psi, respectively, and ductility was 22 percent elongation in 2 inches at room temperature. The tensile strength and 0.2-percent-offset yield strength of rim material at 1200° F were about 70,000 and 63,000 psi, respectively, with a ductility of approximately 20 percent.

The tensile properties of specimens from various locations near the rim of the disc were quite uniform. However, the tensile properties of the specimens from near the center of the disc where the soft spots existed were low. Tensile strength at room temperature was as low as 94,000 psi with an elongation of 7 percent. Corresponding differences were observed in tensile properties at 1200° F.

Rupture Test Characteristics

The rupture test data obtained at 1200° F are given in table II. These data are plotted to the usual double-logarithmic coordinates to give the curves of stress against rupture time (fig. 3). The rupture strength of specimens taken radially from the center of the disc near the rim for definite time periods, indicated by figure 3, are included in table II together with the estimated ductilities to fracture. The rupture strengths were 36,000 and 24,500 psi for rupture in 100 and 1000 hours. The ductility to fracture was approximately 2 percent at both time periods.

Figure 3 also includes a rupture curve drawn through rupture test points obtained for a similar disc of EME alloy by the General Electric Company. It is noted that their disc had higher rupture strengths than the disc tested at the University of Michigan.

Rupture specimens from various locations in the disc were tested for uniformity at a stress which was expected to cause fracture in approximately 100 hours. Rupture times varying from 77 to 429 hours for specimens from the five locations listed in table II indicate that the disc material was not very uniform as measured by the rupture test. Rupture test ductilities of the specimens from the various locations were about the same as the ductilities of center-plane radial specimens with the exception of the specimen from midway between the center and rim of the disc which showed relatively high elongation.

Time-Deformation Characteristics

Curves of stress against the logarithm of the time required for total deformations of 0.1, 0.2, 0.5, and 1 percent at 1200° F for the disc are shown in figure 4. Curves for rupture time and for the transition to third-stage creep have been added in figure 4 in order to describe completely the deformation characteristics of the disc. The data for figure 4 are summarized in table III and were taken from the time-elongation curves obtained from the creep and rupture tests.

The tests conducted were insufficient to establish completely the total-deformation characteristics. Higher deformations than 1 percent were not reported because the total deformations of the specimens were only 1 to 3 percent. As a result of this low total deformation, transition to third-stage creep occurred prior to the time to reach a total deformation of 1 percent. The data were quite erratic and indicate that the specimens cut from various locations differ in their deformation characteristics, particularly during first-stage creep. These variations in deformation during first-stage creep may have been the result of the stresses being above the proportional limit for the material.

Estimated stresses to cause various total deformations in 1, 10, 100, 1000, and 2000 hours, as defined by the curves of figure 4, are given in table IV.

Creep Strengths

Data taken from the time-elongation curves for creep tests, including total deformations in 100, 500, and 1000 hours and creep rates at 500 and 1000 hours, are shown in table V. Minimum creep rates from the rupture tests and the 1000-hour rates from the creep tests are plotted against stress on double-logarithmic coordinates in figure 5. A creep strength of 16,000 psi for a rate of 0.0001 percent per hour was obtained for the disc.

Extrapolation of the transition curve of figure 4 indicates that third-stage creep would not be expected before 10,000 hours under the stress to cause a creep rate of 0.0001 percent per hour. However, extrapolation of the curve of stress against rupture time shows that the 10,000-hour rupture strength is only 17,000 psi. The creep strength therefore is not a particularly safe design stress for 10,000-hour service because it is so close to the rupture strength.

Stability Characteristics

The effects of creep and rupture testing at 1200° F on the room-temperature physical properties, the magnetic susceptibility, and the microstructure of the EME alloy disc were used to evaluate the stability characteristics of this material.

The major change in physical properties was the marked decrease in impact strength during creep testing at 1200° F as is shown by the test data in table VI. The tensile and yield strengths may have decreased slightly although this is difficult to establish because of variability of specimens from such a large forging. Qualitative tests with a magnet indicated that the original material had very little ferromagnetism and that during rupture testing at 1200° F the magnetic response of the material increased.

Photomicrographs of the original material and of specimens after completion of creep and rupture tests are shown in figures 6 and 7. The grain size varied from 4 to 7, being larger near the center of the disc than near the rim. There was a marked difference in the amounts and types of excess constituents present in the structure at various positions. (See fig. 6.) At least two types of excess constituents were present in the original structure. The dark etched areas in the photomicrograph at a 100-diameter magnification of the center of the disc represent one type and the lighter etched areas of excess constituents, the other. The bottom half of the picture at a 1000-diameter magnification shows the first type and the top half, the other type. More and larger areas of excess constituents were present near the center of the disc than near the rim. These excess constituents formed a nearly continuous network near the center.

Some precipitation of fine particles occurred in the structure of the disc during creep and rupture testing at 1200° F. (See fig. 7.) It will also be observed that the structure of the creep specimen was quite similar to the center microstructure shown in figure 6, except that the network of excess constituents had been broken up somewhat. The 1200° F rupture specimen was finer grained, had fewer excess constituents than the creep specimen, and was more similar to the original microstructure near the rim.

Data from Tests in Other Laboratories

Data from The Midvale Company laboratories on several heats of bar stock, in which the EME alloy composition was varied slightly from heat to heat, are given in table VII. The bar stock was forged, rolled down to a temperature of 1350° F, and stress-relieved. The most outstanding properties of these heats were obtained from materials with compositions very similar to that of heat H-4819 from which the disc tested for this report was made. Hardness, tensile, rupture, and ductility properties of the bar stock were higher than that of the disc. Strengths for rupture time periods of 1000 hours at 1200° F ranged from 39,000 to 43,000 psi with corresponding ductilities of 5 to 10 percent.

Data from the General Electric Company laboratories on a disc of similar composition and fabrication to that of the disc tested at the University of Michigan are given in figure 8. The disc was uniform in

hardness and had good tensile test ductility. The reported rupture strengths at 1200° F were 45,000 and 31,000 psi for fracture in 100 and 1000 hours.

General Electric also reported that the good short-time room-temperature properties were borne out in the overspeed tests which were run on five discs. The bursting speeds were as follows:

Bursting speed (rpm)	Increase in diameter after spinning at 22,000 rpm (in.)
22,610	0.102
22,610	.033
23,000	.146
23,133	.045
23,250	.035

These values on bursting were reported by General Electric to be somewhat over the bursting speed which is normally obtained from Timken alloy hot-cold-worked discs. The values for increase in diameter, which were obtained on inspection after spinning at 22,000 rpm, were high, but not excessive.

The discs tested in the programs at the University of Michigan and the General Electric Company were made in the early development stages of EME alloy. The Midvale Company has subsequently improved the forging process and has submitted the survey of room-temperature properties shown in figure 9 as representative of better practice. This disc had somewhat higher tensile strength and lower ductility on an average than the discs previously discussed. The ductility, however, was considerably better at the center soft spots than was the case in the earlier discs. The yield strengths reported for the Midvale disc are based on a higher deformation than an offset of 0.02 percent and are therefore not comparable with General Electric Company values.

DISCUSSION OF RESULTS

The properties of the particular disc of EME alloy studied in this investigation were apparently below the potential properties of the alloy at 1200° F. This appears to be an example of the poor properties which any alloy would show when improperly treated. The disc was made during the early stages of development of the alloy when sufficient experience had not been obtained for a guide in selecting the proper fabricating conditions. Attention was probably focused on the problem of obtaining sound forgings and not on developing the proper control necessary to insure good properties at high temperatures.

The Midvale data for bar stock indicate that the rupture strengths of properly treated EME alloy are much higher than those given in this report for discs. Experience in general with other alloys has indicated that the good properties of bar stock can be developed in large forgings when the forgings are properly fabricated. The information reported is too meager to indicate directly the cause of the low strength of the disc at 1200° F. The chemical composition is very close to the range preferred for the alloy. The physical properties at room temperature are lower than those reported for the bar stock and suggest that the hot-cold-work was not as extensive as in the bar stock. Work on other alloys has in general indicated that hot-working at too low temperatures may interfere with the precipitation reactions which control strength at high temperatures, but the conditions reported do not indicate that this definitely was a contributing cause in this case.

Experience in general indicates that variable strengths at high temperatures may be expected from as-forged materials unless considerable care is exercised in controlling conditions. The higher physical properties and rupture strengths of the similar disc tested by the General Electric Company are evidence of nonuniform production conditions. The disc later produced by The Midvale Company by improved practice had outstanding uniformity of physical properties. The increased strength and ductility at the soft spots in the center were particularly outstanding because low ductility at these points is a major source of trouble in such forgings. Unfortunately rupture data were not available to determine if the strength at high temperatures had also been improved.

The ductility of the discs in the rupture tests was low. This is characteristic of most alloys tested in the form of large discs when they are hot-cold-worked at 1200° to 1350° F. The higher ductility of the bar stock tested by Midvale is characteristic of such materials when hot-cold-worked from 1700° to 1350° or 1400° F, as was the case for the bar stock.

The properties of the EME discs at room temperature compare favorably with those of large discs of several other alloys given in table VIII. The rupture strength, however, was low. The disc tested by the General Electric Company had better, but still low, rupture strength. It should be recognized, however, that the other materials could have lower strengths if the prior treatment is not properly controlled.

The variations in rupture time for specimens from various locations in the disc suggest that the alloy may be somewhat sensitive to the amount and direction of working of the metal. The observed variations in physical properties and grain size are evidence of the presence of nonuniform working of the metal. Probably the highest rupture strength of the various specimens was associated with the larger grain size observed. Experience with other alloys, however, indicates that temperatures and amount of working the metal are of more influence than grain size. The variation in excess constituents could also have been a contributing factor.

CONCLUSIONS

From a study of the properties at room temperature and 1200° F of a rotor disc of EME alloy and comparison of these properties with data on the alloy from other laboratories, the following conclusions were made:

1. When properly fabricated, contour-forged discs of EME alloy have excellent strength and uniformity of properties at room temperature.
2. The properties of discs tested have been low at 1200° F probably because the discs tested were made during the early stages of development of the alloy with insufficient experience in production control to insure good properties.
3. Until further data are obtained, the low properties at 1200° F should be considered only as an example of what could happen to any alloy during early development when insufficient information is available for control of production conditions. Experience in general indicates that the good properties of bar stock can be reproduced quite well in large forgings by proper choice of forging conditions.
4. Sufficient metallurgical experience and data were not available to determine the exact cause of the low strength of the discs. The most probable explanation is that the prescribed processing procedure was not attained during preparation of the disc and adversely affected the properties.

University of Michigan

Ann Arbor, Mich., March 24, 1947

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7. Reynolds, E. E., Freeman, J. W., and White, A. E.: A Metallurgical Investigation of Two Large Discs of CSA Alloy. NACA TN No. 1533, 1948.

TABLE I

SHORT-TIME TENSILE PROPERTIES OF DISC OF EME ALLOY

Specimen number	Specimen location (1)	Temperature (°F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness
				0.02 percent	0.1 percent	0.2 percent				
3Y	CRR	Room	112,500	70,000	87,000	93,000	50,000	20.5	39.1	238
6Y	CRR	Room	112,500	78,500	88,500	93,000	50,000	20	38.5	245
4Z	SRR	Room	113,000	75,500	91,000	95,500	52,500	24	47.3	242
6Z	SRR	Room	112,500	72,000	88,500	94,000	37,500	23	49.5	242
9Y	CTR	Room	112,500	70,000	86,500	92,000	45,000	22.5	45.4	232
9Z	STR	Room	116,000	77,500	91,500	96,000	50,000	20.5	44.8	239
10Y-1	CRC	Room	104,500	62,000	79,500	86,000	30,000	7.5	11.8	226
10Z	SRC	Room	94,000	60,000	76,000	80,000	32,500	6.5	8.1	230
4Y	CRR	1200	70,500	-----	61,000	62,500	27,500	17	39.4	---
3Z	SRR	1200	69,125	-----	61,500	64,000	30,000	20.5	48.4	---
9X	STR	1200	68,750	-----	56,500	61,000	22,500	20.5	42.3	---
10Y-3	CRC	1200	62,875	-----	53,000	56,000	22,500	8.5	15.8	---

- ¹CRR center-plane radial specimen near rim of disc.
 SRR surface-plane radial specimen near rim of disc.
 CTR center-plane tangential specimen near rim of disc.
 STR surface-plane tangential specimen near rim of disc.
 CRC center-plane radial specimen near center of disc.
 SRC surface-plane radial specimen near center of disc.

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TABLE II

RUPTURE TEST CHARACTERISTICS AT 1200° F OF
DISC OF EME ALLOY

Specimen number	Specimen location (1)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
1Y	CRR	50,000	10	11	21.7	-----
1Y	CRR	40,000	54.5	7	9.5	-----
1Y	CRR	35,000	127	2.5	2.0	0.00465
1Y	CRR	30,000	320	2.5	6.2	.00175
3Y	CRR	25,000	685	1	1.2	.00058
3Y	CRR	23,000	1547	2	2.3	.00045
4Z	SRR	36,000	109.5	1	1.7	-----
9Y	CTR	36,000	221	2	3.0	-----
9X	STR	36,000	77	4.5	2.3	-----
6Y-C	CRM	36,000	429	16	21.2	-----
10Y-2	CRC	36,000	131	4	2.3	-----
Rupture strength						
Specimen location (1)	Stress (psi) for rupture in -					
	10 hr	100 hr	1000 hr	2000 hr		
CRR	50,000	36,000	24,500	22,000		
Rupture ductility						
Specimen location (1)	Estimated elongation (percent) to rupture in -					
	10 hr	100 hr	1000 hr	2000 hr		
CRR	11	3	2	2		

- ¹CRR center-plane radial specimen near rim of disc.
 SRR surface-plane radial specimen near rim of disc.
 CTR center-plane tangential specimen near rim of disc.
 STR surface-plane tangential specimen near rim of disc.
 CRC center-plane radial specimen near center of disc.
 CRM center-radial specimen midway between rim and center of disc.

TABLE III

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F

FOR DISC OF EME ALLOY

Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -				Transition to third-stage creep	
			0.1 percent	0.2 percent	0.5 percent	1 percent	Time (hr)	Deformation (percent)
4X	17,500	0.088	1.5	290	^a 2240	----	----	----
1Y	20,000	.099	---	227	^a 1860	----	----	----
3Y	23,000	.115	---	60	450	1375	1300	0.92
3Y	25,000	.125	---	50	252	----	650	.90
1Y	30,000	.150	---	40	228	315	210	.45
1Y	35,000	.180	---	^a 1	58	----	80	.60
1Y	40,000	.205	---	---	34	44	----	----

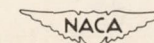
^aEstimated.

TABLE IV

ESTIMATED TIME-DEFORMATION STRENGTHS AT 1200° F
OF DISC OF EME ALLOY

Total deformation (percent)	Stress (psi) to cause total deformation in -				
	1 hr	10 hr	100 hr	1000 hr	2000 hr
0.2	37,500	30,000	22,000	14,000	12,000
.5	-----	-----	31,500	21,000	18,500
1.0	-----	-----	35,500	24,000	22,000
Transition	-----	-----	34,000	23,500	-----

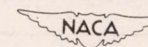


TABLE V

CREEP TEST DATA AT 1200° F FOR DISC OF EME ALLOY

Specimen number	Stress (psi)	Duration (hr)	Initial deformation (percent)	Total deformation (percent) at -			Creep rate (percent/hr) at - (1)	
				100 hr	500 hr	1000 hr	500 hr	1000 hr
4X	17,500	1006	0.088	0.153	0.242	0.325	0.000180	0.000155
1Y	20,000	1058	.099	.169	.250	.343	.000183	.000183

¹Creep strength: Stress for creep rate of 0.0001 percent per hour = 16,000 psi.

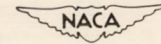


TABLE VI

EFFECT OF CREEP TESTING AT 1200° F ON ROOM-TEMPERATURE

PHYSICAL PROPERTIES OF DISC OF EME ALLOY

Specimen number	Prior testing conditions		Tensile strength (psi)	Residual room-temperature properties							
				Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Izod impact strength (ft-lb)	Vickers hardness
	0.02 percent	0.1 percent		0.2 percent							
(a)	(b)	(b)	112,625	74,000	88,750	93,875	47,500	21.8	43.8	14, 17	^c 241 ^d 245
IY	20,000	1058	-----	-----	-----	-----	-----	----	----	6, 8	258
4X	17,500	1006	111,750	68,000	79,000	84,000	50,000	21.0	36.8	-----	---

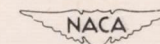
^aAverage of tests on center- and surface-plane radial specimen near rim of disc.^bOriginal condition.^cCenter rim.^dCenter.

TABLE VII

PROPERTIES OF BAR STOCK OF EME ALLOY REPORTED BY THE MIDVALE COMPANY

Heat number	Chemical composition (percent)								Fabrication	Brinell hardness	
	C	Mn	Si	Cr	Ni	W	Co	N			
1479	0.12	0.20	0.33	17.40	10.50	2.81	0.76	0.08	30-pound, 4-inch-square ingots were hammer cogged to 1½-inch-square billets from 2150° to 1750° F. Billets were rolled to ¾-inch rounds from 2100° F. The five final passes which produced a 20-percent reduction were from 1650° F to 1350° F. Bars were heated to 1200° F, 4 hours and air-cooled.	237-248	
1480	.14	.40	.57	19.05	10.60	3.32	1.27	.164		271-277	
1482	.12	.42	.52	19.16	12.16	4.24	1.22	.156		255-258	
1484	.14	.40	.46	18.15	11.42	3.09	1.14	.156		267-281	
1486	.13	.41	.48	19.65	12.13	3.07	1.17	.018		241-252	
Heat number	Tensile properties							Rupture properties at 1200° F			
	Room temperature			1200° F				Rupture strength (psi) in -		Estimated elongation (percent) in -	
	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent in 2 in.)	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent in 2 in.)					
								100 hr	1000 hr	100 hr	1000 hr
1479	125,000	86,500	28	85,500	76,500	15	49,800	39,000	10	5	
1480	145,000	103,000	22	85,000	78,100	14	53,900	-----	16	10	
1482	137,000	101,000	21	84,500	79,000	18	55,600	43,000	10	9	
1484	139,000	100,000	23	84,000	79,000	21	53,000	42,000	20	--	
1486	125,000	85,000	25	78,000	75,000	18	52,000	-----	20	--	

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TABLE VIII
COMPARATIVE PROPERTIES OF DISCS OF EME ALLOY AND DISCS OF 19-9DL, CSA, LOW-CARBON N-155, AND TIMKEN ALLOYS

Alloy	Type disc	Approximate dimensions		Processing (a)				Room-temperature physical properties				Rupture properties at 1200° F for -				
				Heat treatment			Hot-cold-working temperature (°F)	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent)	Brinell hardness	100 hr		1000 hr		
		Diam. (in.)	Thickness (in.)	Tempera- ture (°F)	Time (hr)	Cooling						Strength (psi)	Elongation (percent)	Strength (psi)	Elongation (percent)	
																Rim
EME	Contour	21	4 1/2	6	(b)	(b)	(b)	1240	112,625	74,000	22	230-250	36,000	3	24,500	2
EME ^c	Contour	21	4 1/2	6	(b)	(b)	(b)	1240	124,350	85,425	23	255-277	45,000	2	31,000	--
EME ^d	Contour	21	4 1/2	6	---	---	---	----	127,875	-----	21.8	-----	-----	--	-----	--
^e 19-9DL	Cheese	20	3 1/4	3 1/4	(b)	(b)	(b)	----	104,700	39,275	30	202-208	40,000	27	34,000	16
^f 19-9DL	Contour	20	3 1/2	5	2150	2	W.Q.&g	1250	119,600	70,500	26	246-253	47,000	3	38,500	1
^f 19-9DL	Contour	20	3 1/2	5	2150	2	W.Q.	1650	102,500	39,000	34	200-223	36,500	20	32,000	14
Low-carbon CSA ^h	Cheese	20	3 1/2	3 1/2	(b)	(b)	(b)	----	107,400	40,300	35	200-230	35,500	32	30,000	18
High-carbon CSA ⁱ	Cheese	20	3 1/2	5	2100	(j)	A.C. ^k	1420 to 1250	126,250	47,800	23	230-255	37,000	25	31,500	13
High-carbon CSA ⁱ	Cheese	20	3 1/2	5	2100	(j)	A.C. to 1400° F; 24 hr at 1400° F	1420 to 1250	125,250	50,300	22	230-255	41,000	24	34,000	9
^l Low-carbon N-155	Cheese	21	3 1/4	3 1/4	(b)	(b)	(b)	----	118,290	58,750	35	211-255	55,000	12	42,000	10
Timken ^m	Contour	20	3 1/2	5	(b)	(b)	(b)	1200 to 1300	122,780	76,400	14	250-261	45,500	18	34,000	10
Timken ^m	Contour	20	3 1/2	5	2150	2	W.Q.	1250	135,750	81,000	20	269-299	44,000	2	34,000	3
Timken ^m	Contour	28	2	3 3/4	(b)	(b)	(b)	1275	123,875	72,500	18	248-267	49,000	30	34,000	30

^aEach disc was given a final stress-relief treatment at 1200° F.

^bHot-forged.

^cGeneral Electric Company data.

^dMidvale Company data.

^eSee reference 1.

^fSee reference 6.

^gW.Q., water-quenched.

^hSee reference 2.

ⁱSee reference 7.

^jTime of solution treatment not known.

^kA.C., air-cooled.

^lSee reference 3.

^mSee reference 4.

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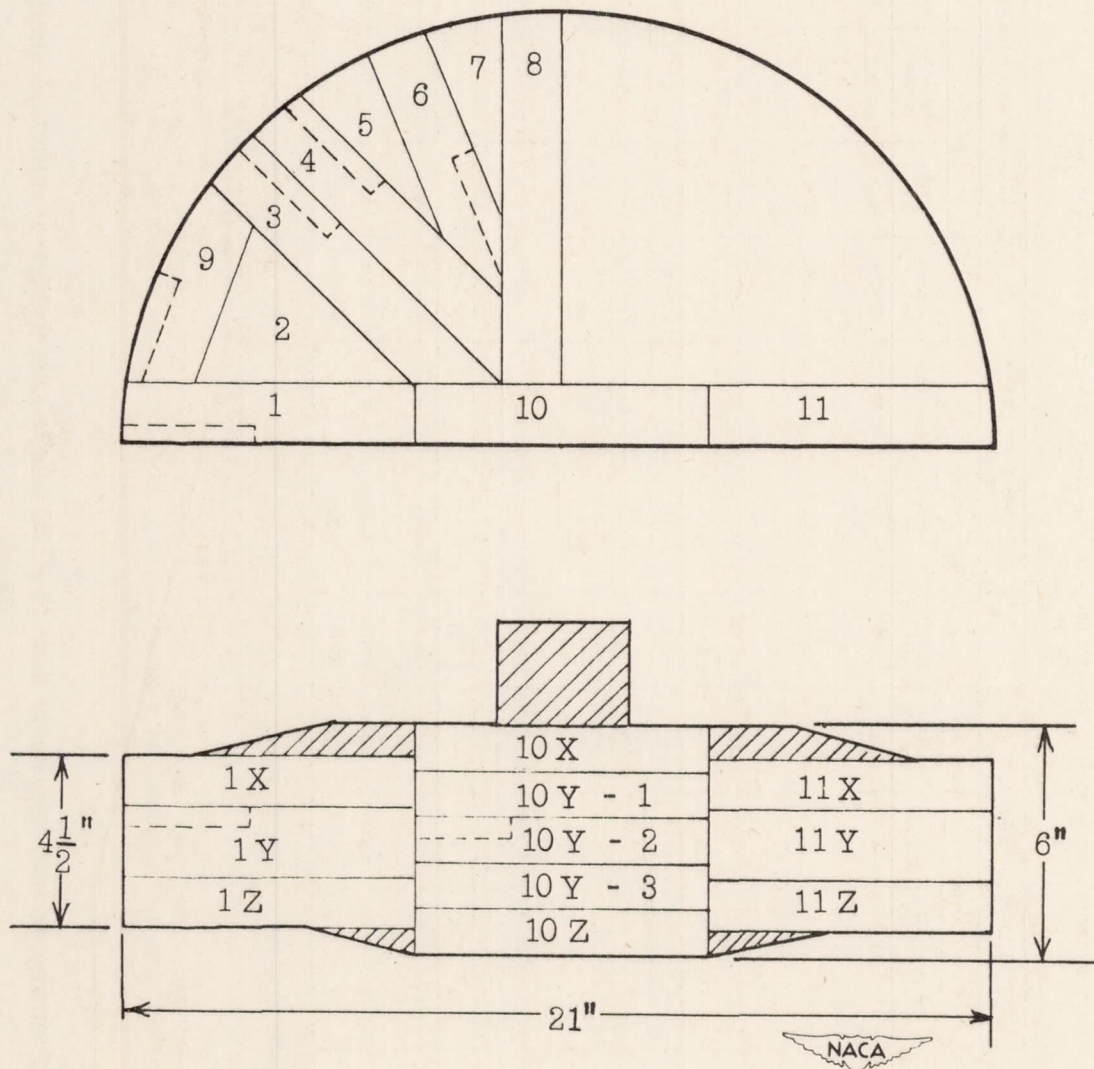


Figure 1.- Location of test coupons in half section of disc of EME alloy.

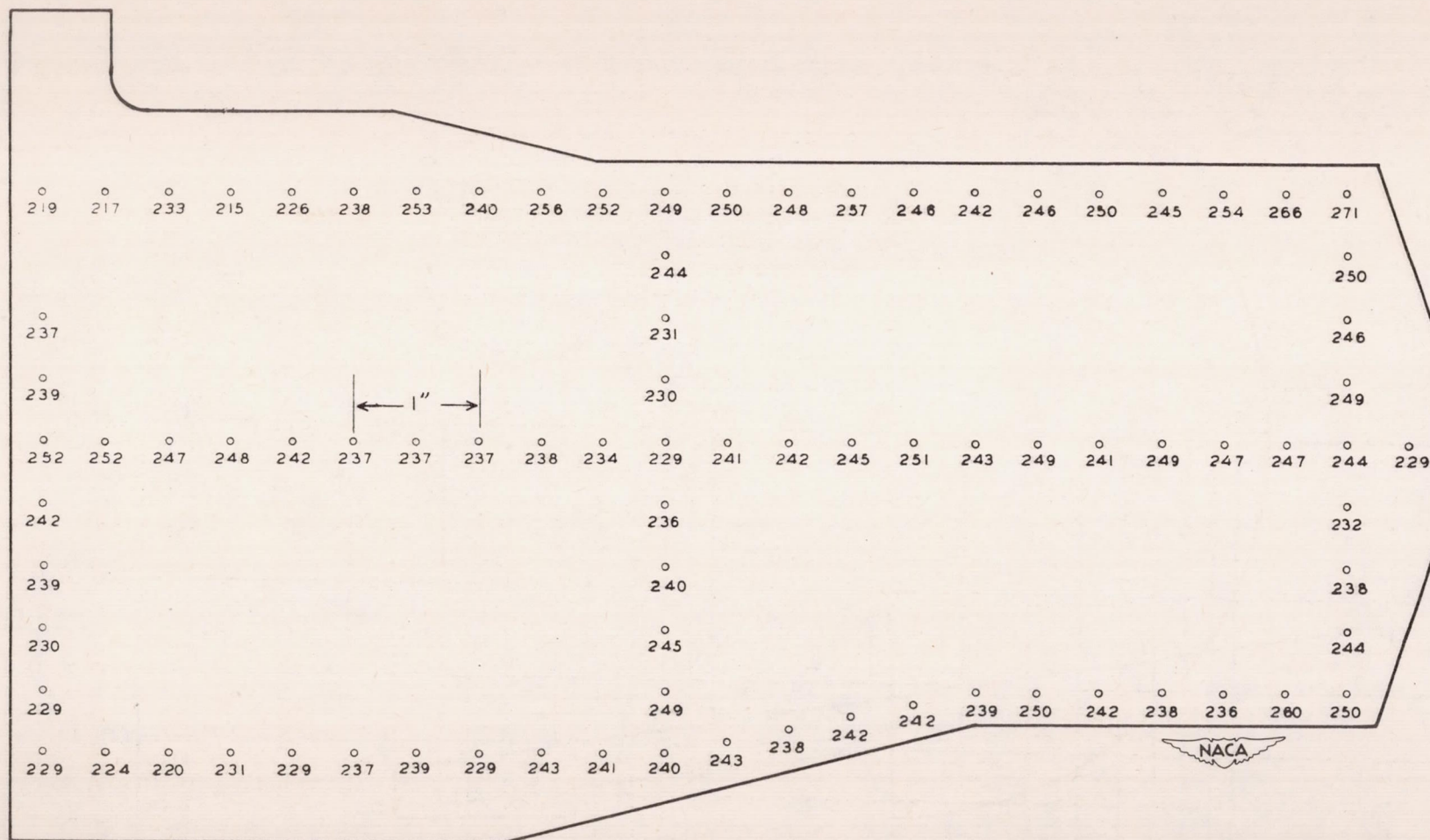


Figure 2.- Hardness survey on half section of disc of EME alloy. Brinell hardness; disc sections 10 and 11.

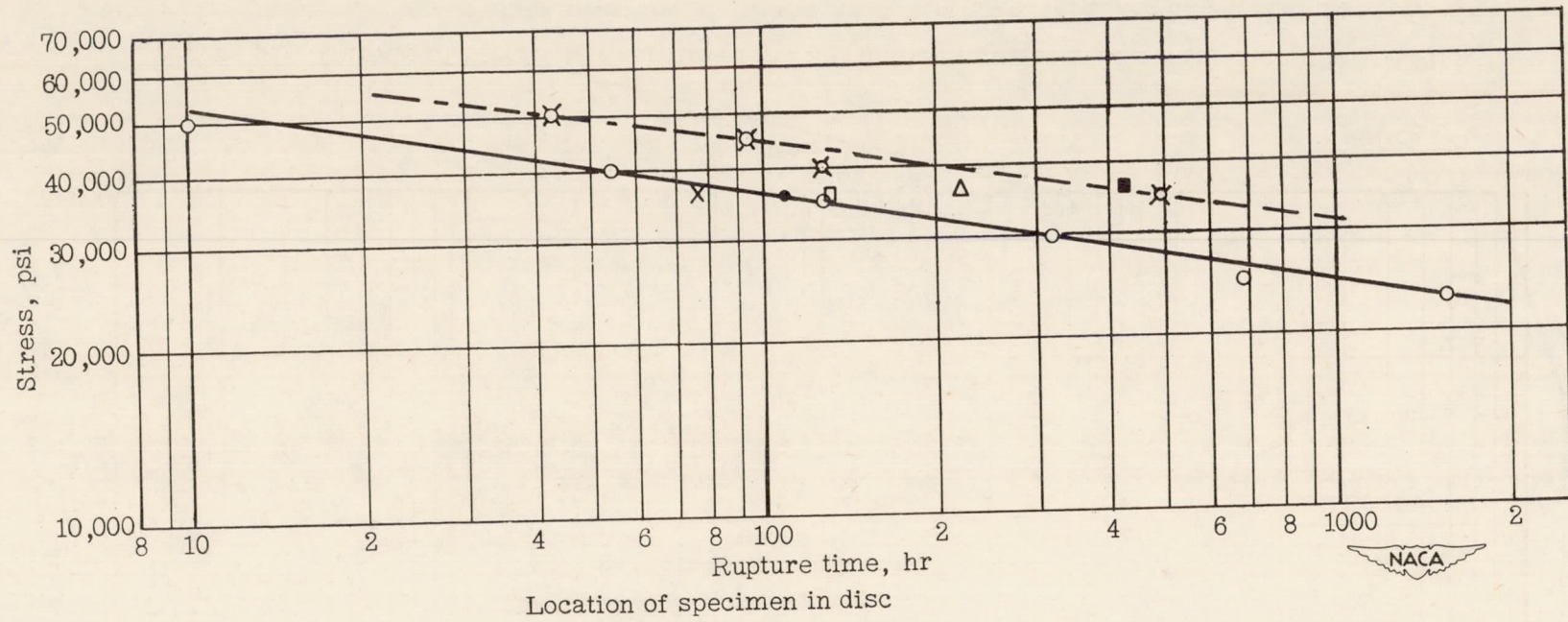


Figure 3.- Curves of stress against rupture time at 1200° F for discs of EME alloy.

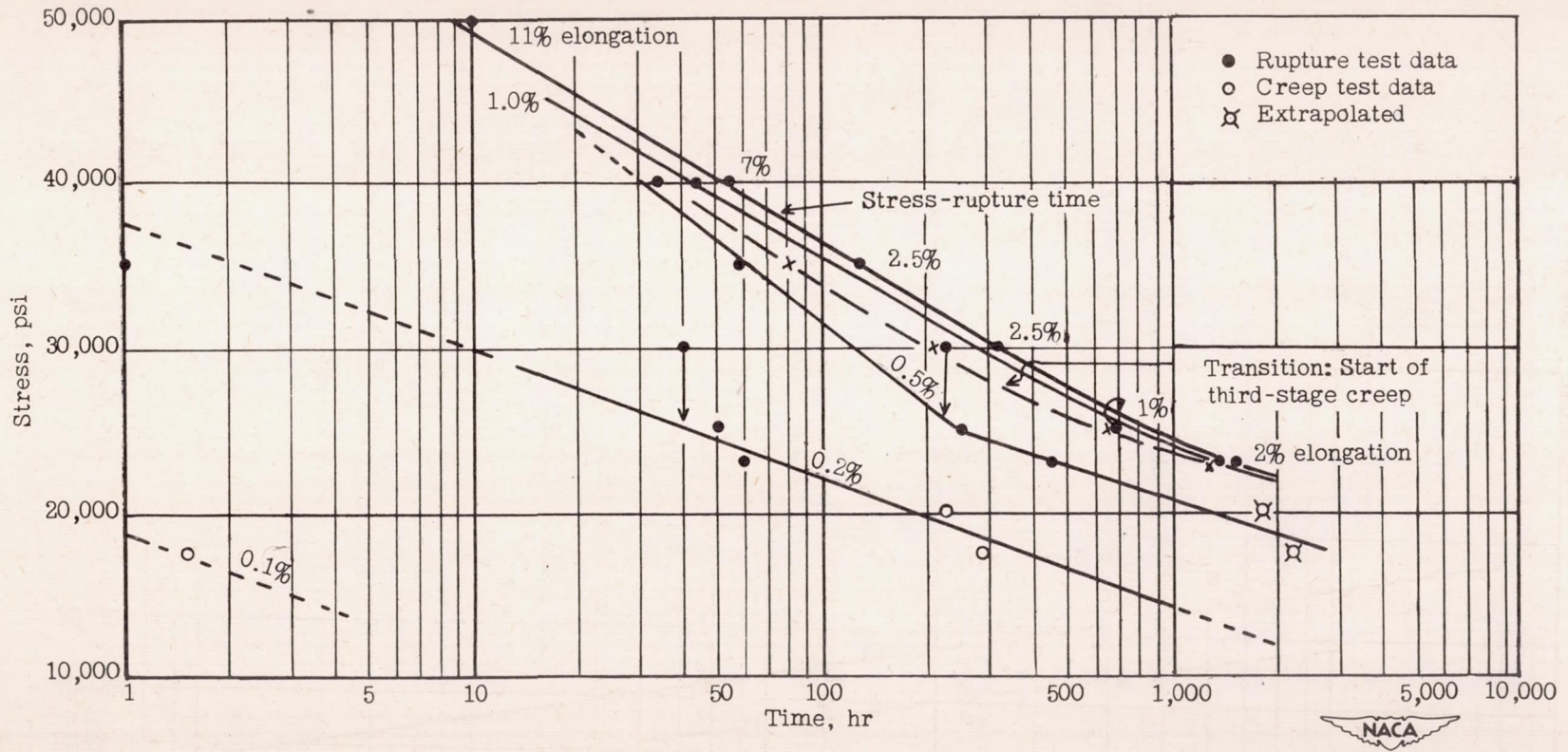


Figure 4.- Curves of stress against time for total deformation at 1200° F for disc of EME alloy.

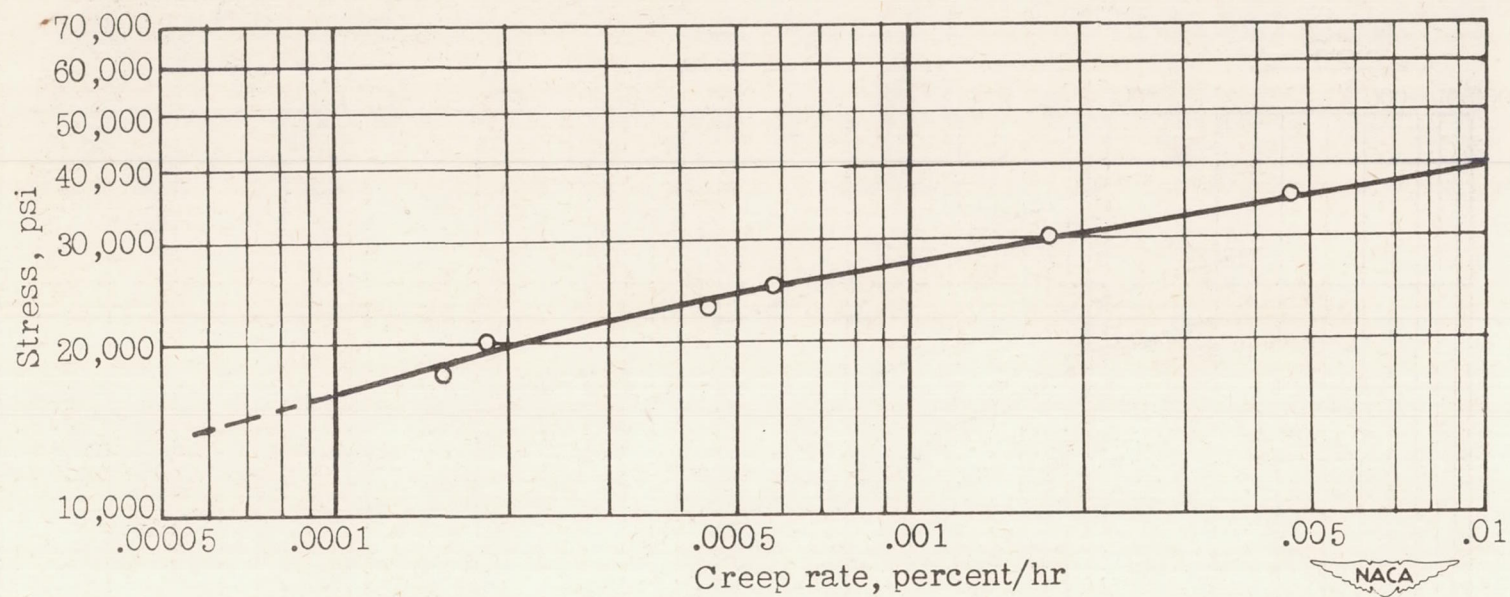
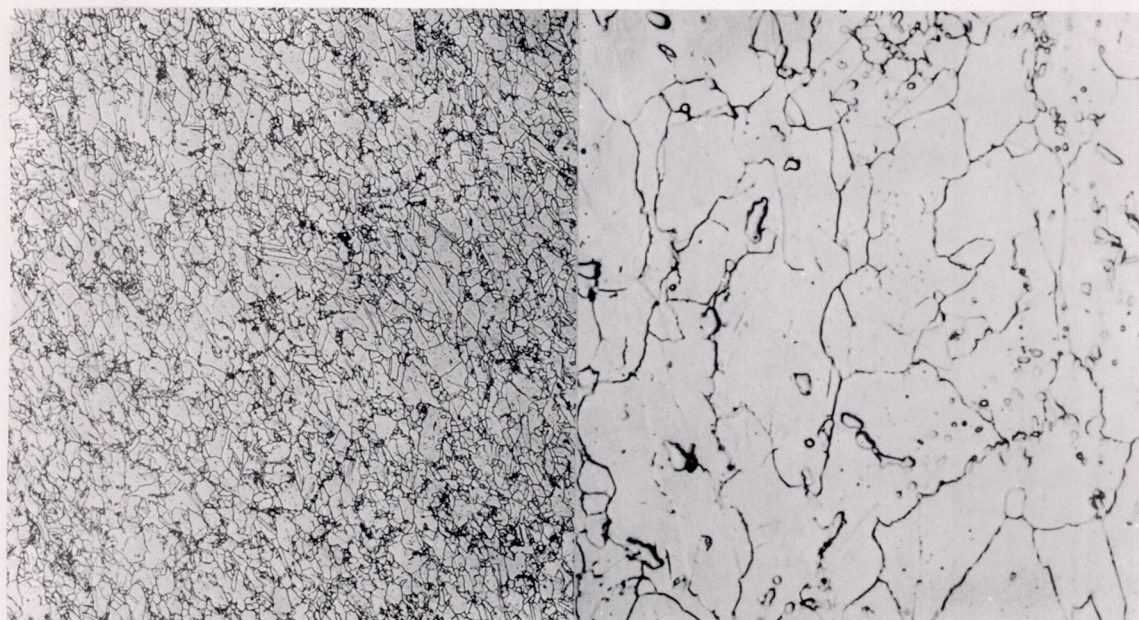


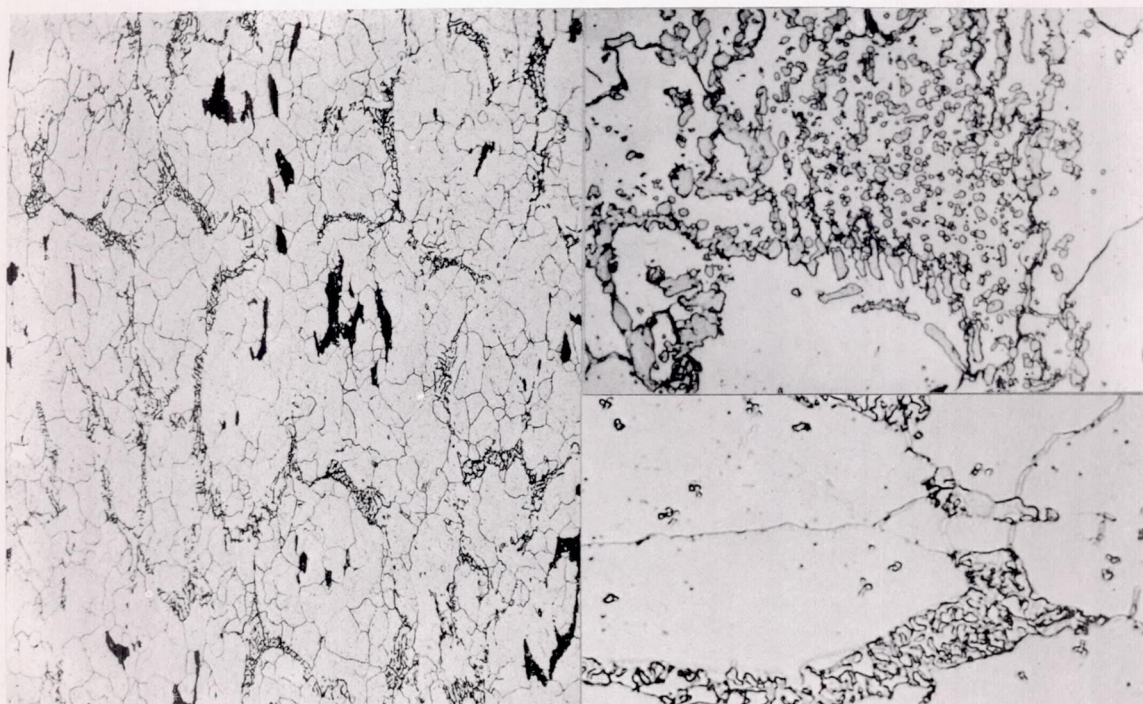
Figure 5.- Curve of stress against creep rate at 1200° F for disc of EME alloy. All data at stresses above 20,000 psi from rupture tests.



100X

1000X

(a) Radial section near rim of disc in Y-plane.



100X

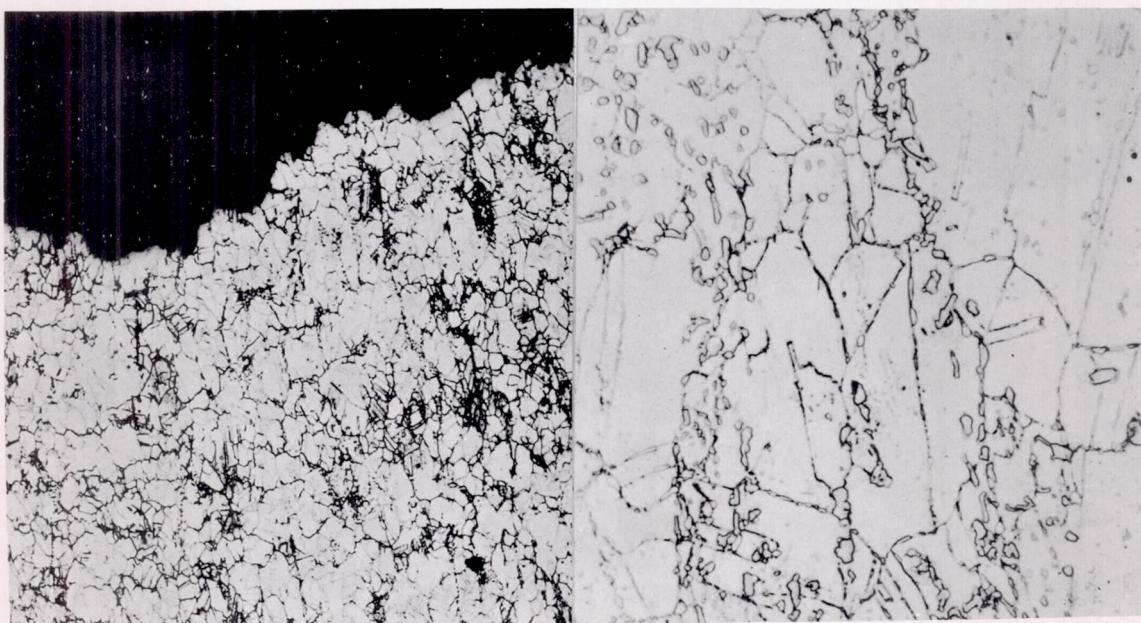
1000X

(b) Radial section near center of disc in Y-plane.

Figure 6.- Original microstructure of disc of EME alloy. Aqua regia in glycerine etch.

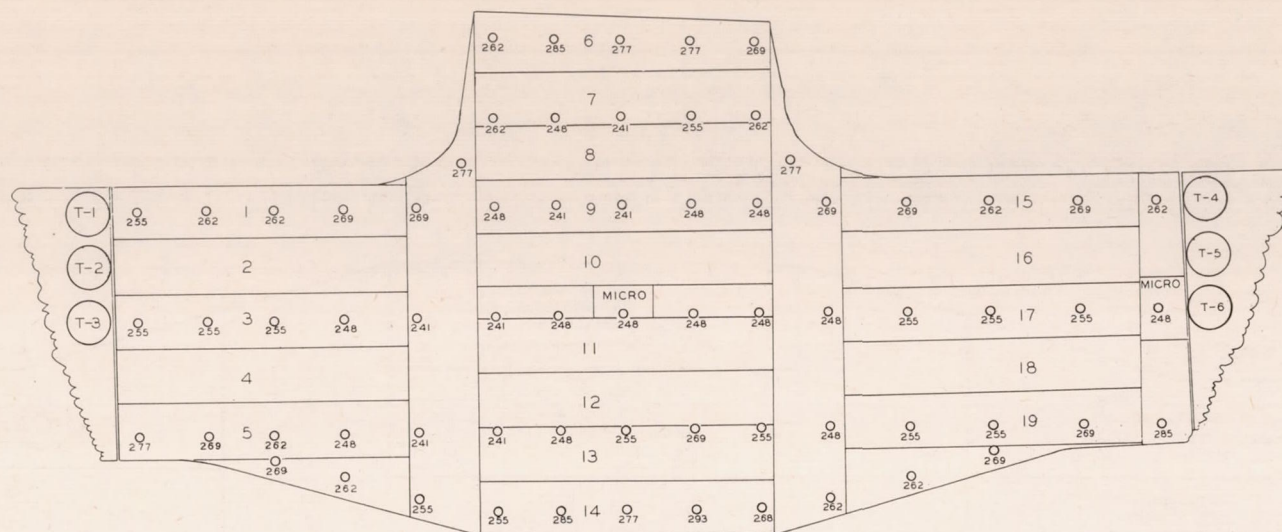


100X 1000X
(a) Creep specimen 1Y; 1058 hours under 20,000 psi.



Fracture - 100X Interior - 1000X
(b) Rupture specimen 3Y; 1547 hours for rupture under 23,000 psi.

Figure 7.- Microstructures of specimens from disc of EME alloy after completion of creep and rupture tests at 1200° F. Aqua regia in glycerine etch.



Tensile properties at room temperature for center and radial 0.505-inch specimens				
Specimen	0.02-percent-offset yield strength (psi)	Tensile strength (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
1	86,625	125,000	24	49.46
2	82,875	124,000	22	44.85
3	85,500	125,000	23.5	41.87
4	87,000	125,000	21	45.73
5	87,750	124,000	21	48.58
6	94,125	124,500	9	27.83
7	82,500	113,500	8.5	35.99
8	72,750	108,500	17	32.78
9	79,125	116,000	19	38.81
10	81,000	124,000	24	43.67
11	80,250	120,500	24	41.57
12	78,375	104,000	20	51.12
13	75,750	112,000	16.5	29.83
14	79,875	116,000	8.5	26.13
15	85,500	124,500	23.5	48.00
16	84,750	123,500	25	44.85
17	85,125	124,500	22	44.55
18	84,375	124,000	20	46.89
19	84,750	124,000	22.5	48.00

Tensile properties of 0.505-inch tangential specimens					
Specimen	Test temperature (°F)	0.02-percent-offset yield strength (psi)	Tensile strength (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
T-1	Room	91,500	125,500	20	45.44
T-2	1200	82,250	77,750	14.5	43.97
T-3	1500	35,250	55,750	20.5	44.26
T-4	1500	36,000	54,500	18.5	50.57
T-5	1200	53,250	78,000	14	44.26
T-6	Room	93,000	124,000	24.5	50.29

Rupture test data at 1200° F for radial specimens at rim		
Stress (psi)	Time (hr)	Elongation in 1 in. (percent)
50,250	42.7	2
45,000	93.9	2
39,750	127.8	2
34,500	499.4	0
100-hour rupture strength: 45,000 psi		
1000-hour rupture strength: 31,000 psi		

Chemical composition (percent)											
C	Cr	Ni	Mo	W	Cb	N ₂	P	Si	S	Mn	Fe
General Electric analysis											
0.13	19.45	10.86	0.06	^a 4.30	0.15	0.013	0.65	0.024	0.61	Bal.	
Midvale analysis											
0.12	19.16	11.92	0.06	3.37	1.23	0.091	0.019	0.66	0.016	0.51	Bal.

^aReported at total oxides.

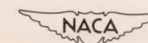


Figure 8.- Tensile, rupture, and hardness data obtained by the General Electric Company on a forged disc of EME alloy supplied by The Midvale Company. Heat number, HF3-15113; hot-forged at 2075°-2100° F; hot-cold-worked at 1240° F; stress relief for 4 hours at 1200° F.

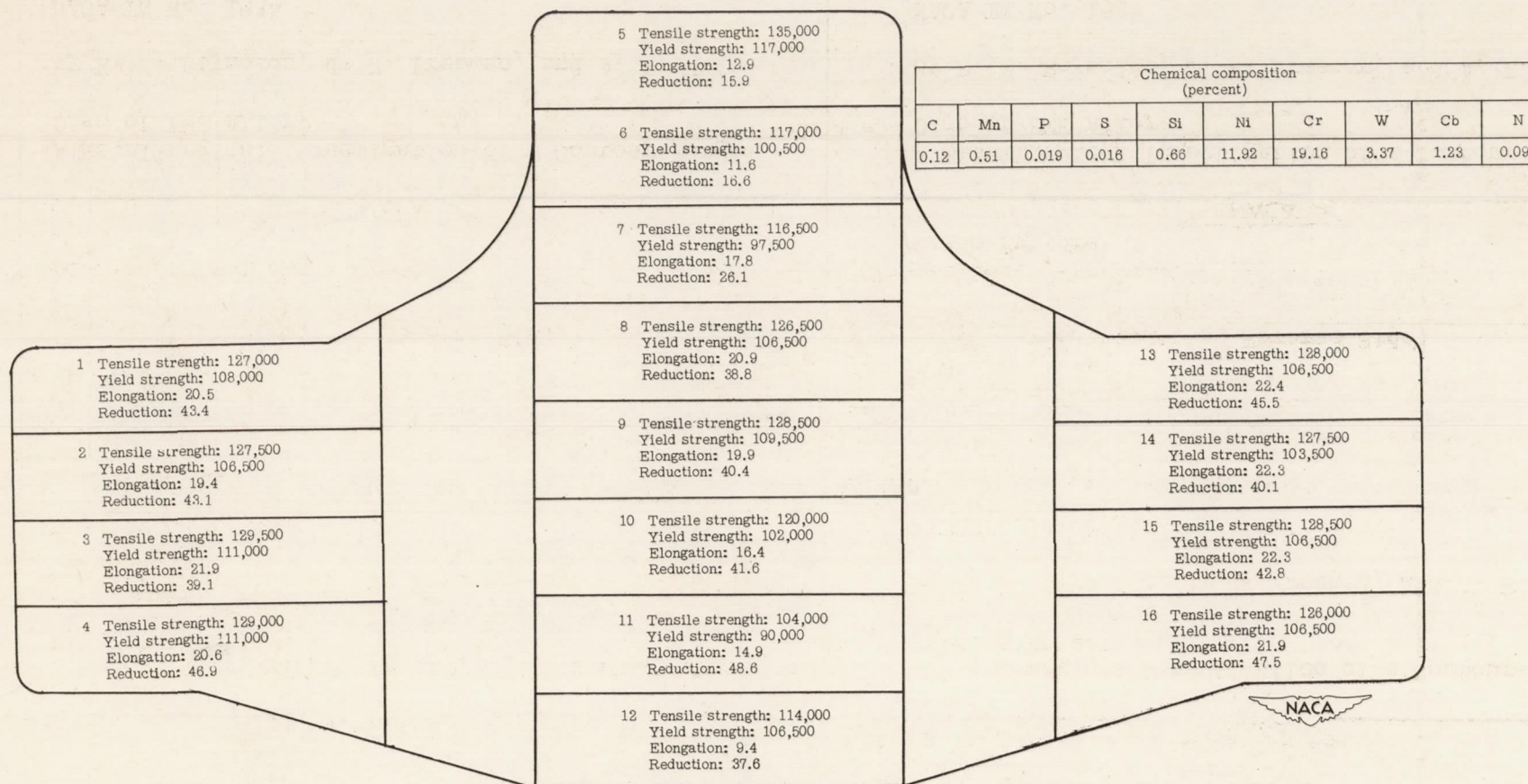


Figure 9.- Tensile properties at room temperature reported by The Midvale Company for a rotor disc of EME alloy made by an improved forging procedure. Heat number, HF3-15113.